The interdependences of BIM and Supply Chain Partnering: Empirical Explorations

Building Information Modelling (BIM) technology and the concept of supply chain management (SCM) could be potentially compatible and mutually interdependent practice. The existing research on BIM focuses on improving project-based and intra-organisational goals, ignoring the impact of BIM on existing structured long-term Supply Chain (SC) partnerships. The purpose of this study is to explore the interdependences of BIM and cross-project long-term inter-organisational teams. Five projects in the Netherlands, with BIM and SCM implementation, were analysed empirically using case study methods, including interviews, documents analysis and live observations. The BIM-enabled SC partnerships adopted various SCM practices and displayed distinct BIM collaboration patterns. This exploration revealed three main patterns of BIM-based collaboration, i.e. *ad-hoc*, *linear*, and *distributed*, in the SC partnerships. The three patterns included various quasi-contractual, physical, and digital means for BIM collaboration. The study suggests implications about BIM researchers and practitioners for not only implementing BIM, but also further integrating the construction SC.

Keywords: building information modelling; BIM implementation; case study; supply chain management; supply chain partnership.

Introduction

The use of Building Information Modelling (BIM) increasingly becomes the norm in Architecture, Engineering and Construction (AEC) as numerous professionals use it. BIM offers benefits not only in design management (Elmualim & Gilder, 2014) but also in project management, i.e. time reduction, communication, and coordination improvement (Azhar, 2011), lower costs and fewer returns for information (Bryde, Broquetas, & Volm, 2013). Currently, there are many discussions about the collaboration benefits of BIM (Barlish & Sullivan, 2012; Mondrup, Karlshøj, & Vestergaard, 2012), but without examining BIM implementation in already structured multi-disciplinary teams beyond organisational barriers, such as contractually-bound supply chain (SC) partnerships.

Information Technology (IT), such as BIM, has been suggested as a key enabler of alliances and partnerships (Rezgui & Miles, 2010). SC partnerships, which consist of multiple sets of dyadic relations from the contractor, use Supply Chain Management (SCM) philosophy to regulate the material and information flows, by encouraging close project-based collaboration and engagement in future projects. SCM entails a set of practices for integrating the project operations within and across projects. These include partner sourcing,

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logistics control, quality management, information management and cultural alignment, among others (Vrijhoef, 2011). The traditional SCM practices are susceptible to either lack or redundancy of information. Accordingly, BIM offers possibilities for consistent information sharing and could bring value in managing the information flows. However, despite their apparent compatibility, the concurrent implementation of BIM and SCM is not yet fully explored.

BIM implementation is usually approached from a firm-related level (Succar & Kassem, 2015). Previous research on the collaboration of various AEC stakeholders through BIM (Cidik, Boyd, & Thurairajah, 2014; Mondrup et al., 2012), focuses on inter-organisational settings from a socio-technical perspective, but not in already structured, and trusting relations, such as long-term SC partnerships. According to Mignone et al. (2016), the BIM collaboration process suffers from discontinuities in the geographic disparity of the BIM users, unbalanced team configuration, and incongruent interests. Both SCM and BIM concepts focus on information flows and affect all actors along the project lifecycle. This study reports on simultaneous BIM and SCM implementation in five real-world cases, by analysing both BIM and SCM in one project per SC partnership. The study is relevant not only to BIM researchers and practitioners but also acts as a proof-of-concept of long-standing visions of partnering the SC, e.g. Egan’s report in the United Kingdom (UK). The aim of this research is to understand:

- how BIM implementation unfolds within projects of SC partnerships;
- the emerging interdependences from aligning BIM with SCM.

The background section discusses the related work, highlights the research gap and presents the research questions. The study uses exploratory case research and presents the results in tables and narratives. The discussion presents the interdependences of BIM and SCM concepts and concludes with implications and suggestions for AEC researchers and professionals.

Background, related research, and gap

Benefits of SCM and BIM

SCM and BIM practices are a hot topic in AEC. SCM is an older concept, which emerged in the mid-80s. It was suggested as a comprehensive management approach to increase customer satisfaction, value, profitability, and competitive advantage (Mentzer et al., 2001). SCM is essentially a management philosophy, and a set of management processes to rationalise the material and information flows (Mentzer et al., 2001). Two main SC thinking schools focus (a) either on the input-output methodology or (b) on inter-firm relationships, e.g. partnerships (London & Kenley, 2001). Gosling et al. (2015) performed a longitudinal study to establish the long-term benefits of partnering and found a direct relation between strategic partnerships and the delivery of consistent performance. This study has focused on SCM practices accompanied by contractual arrangements and strategic visions among the SC partners. Accordingly, the SC partners are divided into internal, i.e. contractually bound or ‘strategic’, and external partners.

BIM is a promising set of technologies for generating, managing, and sharing consistent building information among various AEC actors. The benefits of BIM include several built-in capabilities, such as visualisation and quantity take-off (Eastman, Teicholz, Sacks, & Liston, 2008). BIM has revolutionised design management by offering fluent visualisation, coherent shop drawings, fast coding and accurate interference detection (Azhar, 2011; Elmualim & Gilder, 2014). Moreover, built-in cost estimating features in BIM applications facilitate the work of quantity surveyors and contractors (Azhar, 2011; Bryde et al., 2013). Succar and Kassem (2015, p.65) describe BIM implementation as a “three-phased approach” that includes readiness (pre-implementation), capability (actual implementation) and maturity (post-implementation) that the firms should develop to successfully engage in BIM. As undoubtedly, BIM adoption steadily increases among practitioners, firms, and countries, the inter-organisational BIM collaboration is a hot topic for the AEC industry.

The use of inter-organisational IT has previously supported construction SCM (Rezgui & Miles, 2010). Regarding the information flows of the SC, BIM could sufficiently regulate the building information flows, because it is a structured data model of building information per se (Eastman et al., 2008) and could offer consistent information flows, through open standards, i.e. Industry Foundation Classes (IFC). BIM has also transformed the materials’ cost estimating processes by offering faster and more reliable estimations (Demian & Walters, 2014; Hartmann, Meerveld, Vossebeld, & Adriaanse, 2012). From the above, BIM could sufficiently manage the information and material flows of construction. However, given that the BIM-based collaboration is usually asynchronous because it is not a built-in feature (Cerovsek, 2011; Eastman et al., 2008), the various involved parties have to develop new processes, intra- and inter-organisationally. Cidik et al. (2014) highlight that the actors have to pragmatically tailor their 'design workflow' with the BIM models to their particular discipline-related needs.

Inter-organisational challenges from BIM adoption

The involvement of numerous actors complicates further the BIM implementation. BIM transforms the collaboration among clients, architect, and contractors (Sebastian, 2011). Apart from the designers and contractors, the project initiators (client or owner) and suppliers could play a decisive role as to the implementation of BIM (Nederveen, Beheshti, & Ridder, 2010; Porwal & Hewage, 2013). In their study, Volk et al. (2014) also acknowledge a significant impact of BIM on maintenance and refurbishment phases of the project lifecycle. This increased number of involved parties in BIM implementation is a factor of inter-organisational complexity.

Apart from the number of interested parties in BIM, the frequency and intensity of their interactions dynamically change during a project. Eadie et al. (2013) analyse BIM implementation throughout the UK construction project life-cycle and claim that *"BIM is most often used in the early stages."* BIM use during construction creates a mismatch at the division of labour among the partners that increases complexity (Mäki & Kerosuo, 2015). The extent of the actors' involvement throughout the lifecycle of a BIM-based project varies. Cao et al. (2014) have catalogued thirteen different activities where BIM is applicable, e.g. design exploration and coordination, cost estimation, clash detection, quantity take-off. The varying applicability of BIM to phases and activities in AEC influence BIM implementation. To control this varying applicability of BIM across the phases and actors, and prescribe BIM implementation, various National initiatives suggest quasi-contractual means of BIM-related agreements among the actors, e.g. pre-contract BIM Execution Plan' (CPIc, 2013) under the efforts of the UK BIM Level 2, and 'BIM Protocol' Norm issued by the Dutch Government Building Agency (GBA) (Rijksgebouwendienst, 2012), both of which are inspired from the Norwegian equivalent 'BIM Manual' (Statsbygg, 2011).

In a project with numerous BIM-using firms, the dynamics of the project-based BIM goals constantly change, given that the firms carry various BIM readiness, capability and maturity levels, because of their different disciplines and sizes (Succar & Kassem, 2015; Succar, Sher, & Williams, 2012). Mondrup et al. (2012) highlight that the varying capabilities among the collaborating firms often result in misunderstandings. Harty and Whyte (2010) claim that there is a lack of understanding of the role that digital technologies, such as BIM, play in projects, and especially how the actors' BIM knowledge is accordingly transferred. Meanwhile, a recurring challenge has been the need to inspire and retain trust throughout BIM-based collaboration among extended multi-disciplinary teams (Cao et al., 2015; Miettinen & Paavola, 2014). Trust also influences the sharing of risks and rewards and together with commitment leads to closer SC cooperation (Mentzer et al., 2001). Therefore, BIM could potentially overcome these inter-organisational barriers if applied within already structured environments, such as SC partnerships. Accordingly, the structured environment of SC partnerships could offer fresh insights into BIM implementation.

Research gap

The previous sub-sections underlined that BIM technology and SCM theory could support one another and counterbalance certain inter-organisational challenges. Nowadays, the criteria of SC partner selection process have transformed from price- to collaboration-based (Pala, Edum-Fotwe, Ruikar, Doughty, & Peters, 2014; Sporrong & Kadefors, 2014) or require the use of IT, e.g. BIM (Mahamadu, Mahdjoubi, & Booth, 2014; S. Y.-L. Yin, Tserng, Toong, & Ngo, 2014). Simultaneously, the size of the inter-organisational teams, the intensity of their interaction and trust are non-negligible parameters for BIM implementation. This study explores the real-world combination of BIM and SCM concepts. This combination, hereafter referred to as BIM-enabled SC partnering, denotes practices of contractually-bound SC partnerships that apply BIM.

From the above, there is a lack of understanding of how the mutual dependence, i.e. interdependence, of BIM and SCM could facilitate a SC to achieve its goals through BIM. First, BIM implementation resembles a complex network, because various actors are involved, beyond the design team, such as clients and asset owners (Love, Matthews, Simpson, Hill, & Olatunji, 2014; Son, Lee, & Kim, 2015) and suppliers. Second, the existing approaches to alliances tend to be more IT-driven and less inter-organisational even in long-term collaborative ventures, such as SC partnerships (Rezgui & Miles, 2010). Therefore, this study explores BIM implementation within SC partnerships, by focusing on the following research questions:

- How is BIM implemented within projects of SC partnerships?
- What are the interdependences between the concepts of BIM and SCM?

Methodology

Research rationale

Case study research is a popular research method, which focuses on in-depth analysis of phenomena by providing a "real-life context" (Yin,1984). This study used case study methods for exploring the alignment of SCM with BIM concept in their "natural setting" (Benbasat, Goldstein, & Mead, 1987), aiming to provide insights into other inter-organisational BIM settings. Case studies emphasise on the richness of the analysis, rather than its potential generalisation. However, as Bengtsson and Hertting (2014) state that case study methods could facilitate a potential generalisation based on "expectations about similar patterns of thinly rational action and interaction in similar contexts", i.e. other BIM-enabled SC partnerships.

The qualitative case study research was used for two main goals. First, the goal was exploratory to respond to the 'how' research question. Second, to respond to the 'what' question, the goal was explanatory, i.e. to evaluate the practical interdependences of BIM and SCM. Throughout this study, these different goals are underlined by different data analysis methods. Before presenting the case study design and protocol, a brief discussion of the wider research setting and the case selection criteria will intervene.

BIM and SCM in the Dutch AEC

The Dutch AEC was selected as the setting of these qualitative case studies on the alignment of BIM and SCM. Three reasons explain the selection of the Dutch AEC: the (a) attention given to partnering and SCM, (b) affinity to innovation regarding BIM, and (c) idiosyncrasy of the Dutch market that could potentially allow for generalisation.

First, the concept of SCM has been diffused in the Netherlands, following the *Rethinking Construction* movement, which originated in the UK around 1998. Later, the Dutch firms looked collaboratively into cost reductions and long-term mutual financial benefits (Vrijhoef, 2011). Second, the Dutch AEC is keen to adopt integrative innovations, such as Integrated Project Delivery, BIM and SCM (Wamelink & Heintz, 2015). The Dutch construction market has been quite proactive in BIM-related initiatives, for example in developing BIM assessment tools after popular demand of AEC firms (Sebastian & Berlo, 2010). Third, according to Dorée (2004), the "efforts to reduce risks and uncertainties are engrained in Dutch culture" and this could explain this market's eagerness to self-regulate regarding BIM. Given that the Dutch AEC has been proactive and consensus-seeking, any lessons-learned from this smaller and reactive market might accordingly reflect future trends to larger construction markets.

Case selection

A set of selection and diversity criteria was used to ensure the relevance of the cases to BIM and SCM concepts, and additionally allow for diversity, research reliability and generalisation. Table 1 contains these criteria:

Table 1: Case selection and diversity criteria.

	Criteria	
Goal	Multi-team	Criteria
Selection	Team	A multi-disciplinary SC partnership across engineers, contractor and supplier.
	History	The SC partners had collaborated before on at least one other project and one or more contractual relations, i.e. framework agreement, exist.
	Vision	The SC partnership expresses a clear vision for future collaboration.
	Technology	Use of BIM-based tools from at least one SC partner.
Diversity	Type	Building construction: multi-functional (MF), housing or utility building.
	Scale	Small (up to 2,000 m2) to large (more than 20,000 m2) projects.
	Size	Small-medium Enterprises (SME) or Multi-National Companies (MNC).
	Boundaries	Local or national character of the SC partnership.

A sample of fourteen construction projects in the Netherlands was evaluated as to the above criteria by a short intake interview, before the official launch of the study. Afterwards, five cases that fit the research timeline were selected. All cases were studied between definitive design and pre-construction. Both recently completed and ongoing cases were explored, to avoid any biases pertinent to impression management or retrospective sense-making (Eisenhardt & Graebner, 2007, p. 28). Leonard-Barton (1990, p. 255) claims that this type of synergy between completed and ongoing cases increases research validity. For confidentiality, the cases are referred to as A, B, C, D and E, sorted in recruitment order.

Case study A is a complex multi-functional (MF) project, which consists of three buildings with 255 residential units, offices and commercial spaces. The complex is next to a canal and its construction is expected to last sixteen months. Case study B concerns a large housing tower, with 83 flats and high technical complexity (Figure 1a). Case study C is a recently completed project, which included an industrial building, exhibition, and offices. The construction of project C lasted about six months, due to a high degree of repeatability and off-site fabrication (Figure 1b). Case study D concerns a small and simple industrial and office space and its construction is expected to be complete in nine months. Case study E is a recently completed project with 44 residential units arranged in two rectangular volumes.

Figure 1: Under-construction housing tower building project of case B (left), and the interior of utility building of case C (right).

Table 2 shows an overview of the cases' selection and diversity criteria. The first column to the left contains the project identifier. The following four columns include the selection criteria. The last five columns contain the diversity criteria and projects' status. The exploration observed repeatable and distinct patterns, and thus, the case selection was considered saturated.

Table 2: BIM-enabled SC partnership case description as to case selection and diversity criteria.

	Selection criteria				Diversity criteria				
	Multi-team	History (projects)	Vision	BIM	Type	Scale	Size	Boundary	Status
A	Yes	2	Unclear	Yes	MF	Large (L)	MNC	Local	Ongoing
B	Yes	10	Yes	Yes	Housing	L	SME	National	Built
C	Yes	7	Unclear	Yes	Utility	Mid- (M)	SME	National	Built
D	Yes	8	Yes	Yes	Utility	Small (S)	SME	National	Ongoing
E	Yes	3	Yes	Yes	Housing	M	MNC	Local	Built

MF: Multi-functional project, MNC: Multi-national Companies, SME: Small-medium Enterprises.

Case study design

From the five cases, data were collected from interviews and observations in three phases:

- Phase I: SCM analysis: Questions about history, and vision of SCM;

- Phase II: BIM analysis: Questions about BIM implementation and application areas and observation of ‘BIM meetings’;
- Phase III: Reflection on BIM-enabled SC partnering: Questions about the outcome of the practices.

The questions for each phase are included in the Appendix. The data from the interviews of Phase I and II were analysed with descriptive statistics, because the questions were closed, and presented in a tabulated form to facilitate the case comparison. The open questions of Phase III were analysed with qualitative analysis software using free codes, regarding aspects of BIM and SCM. Phase III included the feedback from the three completed cases.

Case study protocol

Given that a Supply Chain is a distributed network, an equally distributed data collection method was used. The selected method could be considered a corrective action to the existing SCM theories, which has been focusing more on isolated dyadic relationships neglecting any holistic considerations, as Fernie and Tennant note (2013, p. 1049). This research did not concentrate on the ‘focal’ firm of the SC, instead sought equivalent input from all firms. The projects were followed for between 12 and 18 months, depending on the scale of the project, and 44 professionals from 31 different firms were interviewed. The data collection involved four activities:

- 13 group interviews (group statements) from the SC actors;
- Review of project documents, i.e. five SC contracts and threeBIM protocols;
- Three on-site visits and six meeting observations;
- 13 individual interviews with case participants (interviewees).

All cases included group interviews among the internal SC or the whole SC. The group interviews lasted one hour and a half and aimed at limiting the informant bias and reflecting on their collective understandings. First, the group interviews were initiated with a short introduction about the position of the interviewees inside their firm. Subsequently, each question was addressed to the first interviewee to the right of the interviewer and then next to their right had the opportunity to add to or improve the answer. This process was repeated until all interviewees were satisfied with the collectively registered answers.

The individual interviews were shorter (45 minutes long) and took place after the group interviews to cross-evaluate the previous findings and to deepen the case exploration and mitigate any interviewees' biases. Multiple informants, with diverse functions, e.g. BIM modellers and project managers were interviewed per organisation. Table 3 shows per case the data collection phases and data sources.

Table 3: Data collection sources per case and an indication of the phase where it took place respectively.

	Phase I	Phase II	Phase III
A	1, 2, 3, 4	1, 2, 4	Ongoing project
B	1, 2, 3, 4	1, 2, 3, 4	1, 5
C	1, 2	1, 2	1, 5
D	1, 2, 4	1, 2, 4	Ongoing project
E	1, 2, 3	1	1, 5

1: Group interviews, 2: Analysis of documents, 3: Visit site, 4: Observation of meetings, 5: Individual interviews.

All interviews had the same preparation, administration, and information handling. Before the interviews, all interviewees had the same information about the study via a template email sent. All relevant project documentation was reviewed beforehand. Question hand-outs were administered during the interview. The language was English or Dutch. The interviews were recorded with the interviewees' permission to facilitate the transcription. The interviewees welcomed the used of information for research but preferred to stay anonymous.

Case results: Description, analysis, and interpretation

Description and analysis of SCM (Phase I)

The cases had various SC team compositions and spread along different project phases. The partners varied depending on the technical challenges of the project and SC investment ambitions. In all projects, the contractor was internal SC actor. The rest of internal SC actors belonged in both the front SC part (from initiation to design), e.g. clients and designers and the back SC part (from construction to operation), e.g. installation firms and suppliers. The team of the internal SC actors, up until pre-construction, was formed as follows:

- Case A: The contractor, structural engineer, energy advisor, heating, energy and plumbing, client, and facility manager firms.

- Cases B, C, and D: The contractor, architect, structural engineer, steel sub-contractor and suppliers, e.g. windows, cladding, roof, firms. For case C, the client (investor) was also an internal SC actor.
- Case E: The contractor, architect, structural engineer, heating engineering and installation firms.

Table 4 illustrates the SCM activities per case. The first column to the left contains the project identifiers (A, B, C, D and E). The rest columns include SCM activities for achieving SC integration. Vrijhoef (2011, p. 225) categorises eleven activities that could incite greater integration among the SC actors. The cells contain the descriptions ’Yes‘ and ’No‘ when a particular activity was on not applicable in the cases, respectively. The data were obtained from the closed questions of the intake interview and Phase I (Appendix). The last column calculates the outcome of the factors present in each case and the total number of factors to present the relative SCM maturity across the SC partnerships.

Table 4: SCM activities that contribute to SC integration (column list adapted from Vrijhoef (2011)).

	Repetitiveness	Integration of business activities	Partner sourcing	Integration of operations	Logistics control	Quality management	Information exchange	Product development and design	Market approach and marketing	Cultural alignment	Human resource management	Total number of present factors
A	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	7/11
B	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	8/11
C	No	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	No	6/11
D	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	8/11
E	No	No	Yes	No	Yes	No	Yes	Yes	No	No	No	4/11

Description and analysis of BIM (Phase II)

BIM implementation across phases

The cases presented BIM use in various instances. BIM was used in the preliminary design (PD), definitive design (DD) and technical design (TD) phases for every case. At times, BIM was used in construction for generating the materials’ quantities and volumes and planning and optimising of the site logistics (cases A, B, and D). In the cases A, B, and D they aspired to use BIM during operation. BIM was used only during a few of the areas, where – according to literature – it is usually applicable (Cao et al., 2014). Table 5 presents an overview of the BIM applications, catalogued by Cao et al. (2014). The first column to the left contains the project identifier. The table cells contain the descriptions ‘Yes’ and ‘No’ when a particular BIM application did or did not take place, respectively. The data in Table 5 have derived from the questions of the intake interview and of Phase II (Appendix) and live observations. The most popular BIM applications were three-dimensional (3D) representation, design coordination, clash detection (Figure 2), and quantity take-off. BIM was rarely used for cost estimation, energy simulation or site management.

Table 5: BIM application areas per SCM project (column list adapted from Cao et al. (2014)).

	Site analysis	Design exploration	3D representation	Design coordination	Cost estimation	Energy simulation	Clash detection	Construction system design	Schedule simulation	Quantity take-off	Site resource management	Offsite fabrication	Total number of present factors
A	No	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	7/12
B	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	7/12
C	No	No	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	5/12
D	No	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	6/12
E	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No	4/12


Figure 2: Typical clash session with the installation disciplines (Case A).

SC collaboration via BIM

The firms that participated in the study displayed varying BIM readiness levels. In decreasing order of BIM experience, the SC of case E had two past BIM-based projects, A had one and B, C, D had sporadic BIM applications respectively. The BIM implementation was evaluated by analysing the physical BIM meetings and the digital collaboration processes. The five cases were found to display three levels of BIM-based collaboration: *ad-hoc, linear,* and *distributed*, in increasing order of sophistication. *Ad-hoc* or impromptu BIM collaboration was observed in case E, where BIM was not a contractual requirement. Few actors used BIM, and the contractor was responsible for coordinating their BIM models occasionally by exchanging proprietary (native) BIM files. The exchange of two-dimensional (2D) drawings, frequently and iteratively, was greatly encouraged and thus, the building information was unevenly shared among the SC actors.

Linear BIM collaboration pattern was observed in projects C and D. Most actors used BIM, apart from some suppliers. The BIM collaboration took place by merging 'aspect (or reference) models' to one with model checker software, via IFCs. The collaboration is described as linear because the contractor, who was in charge of model's federation, had separate and on-demand BIM sessions with each actor, similar to the 'over-the-wall' process, and informed the rest by e-mails. The building information was quite uniformly shared among the SC partners, but some redundancy was observed in the exchange. The SC actors in these cases relied more on the underlying informal relations of their SC partnership.

Distributed BIM collaboration pattern was observed in case A and B. The contractor was responsible for merging 'aspect models' weekly with model checker software, similarly to the aforedescribed *linear* process. The coordination of their activities was achieved by hosting pre-scheduled joint *BIM meetings*. The clients occasionally attended these sessions to ensure their requirements were met. The building information was more uniformly shared among the SC actors. Table 6 summarises the above three categories, based on data from live observations of the BIM sessions, document analysis of the BIM protocols, and from the answers received to the questions of Phase II (Appendix).

Table 6: Observed patterns of BIM-based collaboration among the SC partnerships.

		Pattern		
Aspect	Observed feature	Ad-hoc	Linear	Distributed
Actor	BIM as a contractual requirement	-	-	Yes
	BIM-savvy strategic partners	-	Yes	Yes
Process	BIM-related meetings	On-demand	On-demand	Pre-scheduled
	Co-location practices	-	On-demand	Predefined
	Use of Common Data Environment	-	-	Yes
Product	Use of firm-based BIM protocol(s)	Yes	Yes	-
	Compliance to one BIM protocol	-	Yes	Yes
	Model checking tools	-	Yes	Yes
	Information exchange file type(s)	CAD/PDF, Native	CAD/PDF, Native, IFC	Native, IFC
	Deliverable file type(s)	CAD/PDF	CAD/PDF, IFC	CAD/PDF, IFC

Reflection on the combination of BIM and SCM (Phase III)

The cases were not at the same stage when recruited. Given that they had diverse briefs and end dates, only three projects have been completed to now. The reflections on BIM-enabled SC partnering were obtained from the built projects (B, C, E) .The sample was representative because it featured all three emerged BIM collaboration patterns, i.e. *ad-hoc, linear* and *distributed.* The actors' reflections first present the project's outcome,, second the inter-organisational relations, and third conclude with their future approach to improve the alignment of BIM and SCM.

Case B was delivered on time and budget, but time pressure was reported and attributed to the initial commercial decisions taken by the tender managers. Given that the various partners had very dissimilar BIM skills, BIM was not smoothly implemented. For example, some construction mistakes were made, and were discovered and corrected on site (brick fittings in the pre-cast concrete).The architects and the mechanical engineers reported that they were learning from project to project: "*Everyone wants to optimise their own product."* Concerning the practices to support BIM implementation, the architects reported that: *"with the co-locations it was easier than calling to arrange something. We learned a lot by making errors, and we want to sit together more frequently now"*. In the future, they want *"to plan in greater detail when each company receives and delivers their BIM"* (Architect-BIM modeller). Regarding SCM, the main challenge was that some actors prioritised their intra-organisational planning rather than respecting the joint SC planning. Thus, the partners agreed that in the future they would *"try to involve the suppliers who are SC partners even earlier in the design process."* Concerning BIM, the partners concurred that they should clarify their agreements about the Level of Detail (LoD) in advance and improve their BIM strategy.

The project of case C was delivered timely with no cost overruns. However, the partners concurred that all of them had "*unfortunately underestimated the project complexity*." From the partners, only the cladding supplier was advised to improve their quantity and cost calculations. Poor time management was occasionally reported. The contractor advised the steel sub-contractor to "*respect the agreed deadlines when delivering the drawings*." TD was the most challenging phase, and to improve it, closer collaboration between architect and structural engineer was suggested. The partners unanimously decided to densify the joint sessions and choose an appropriate location and period for team co-location in the future. Concerning their daily communication, the partners noticed that "*exchanging 2D drawings was most beneficial because it was faster and more efficient for all*." The contractor suggested that the architects would standardise their mostly used technical details in BIM. Regarding the composition of the SC partnership, the contractor's site manager stated: "*we would like to partner with more specialties, we are looking for it, but none of our preferred partners look suitable,*" as to price flexibility and cultural alignment. They agreed mostly to revise their BIM, rather than SCM strategy in the future.

The project of case E was delivered timely, but the SC partners had to absorb cost overruns that exceeded the tender agreement with the client. The client (external SC actor) stated: "*We do not use BIM in our organisation, but we view it as a method to minimise the faults and improve the quality of the chain.*" The senior architect stated: "*the combination of SCM and BIM is very focused on the second stage of design phase (and) there are benefits that have not been exploited yet*." He added that whereas "*not all architects are really aware of what SCM could mean for their work*," his firm is "*actively pursuing more SC collaborations*." Further, the contractor's site manager stated that "*BIM is the future; it is efficient and eliminates extra costs, yet they double-checked all calculations manually for the quantities*". BIM was used only during PD, DD, and TD. The partners exchanged 2D drawings and native BIM files. Some firms had their own BIM protocol, but no joint BIM protocol plan was applied. They only analysed the clashes and observed some improvements during the TD phase. Concerning the SCM strategy, the contractor's tender manager mentioned: "*we are very satisfied (but) we are now busy with changing the composition of the chain (…) we want more proactive partners*". The actors concurred with: "*we have never performed a project evaluation among the chain partners (…) it is not yet in our culture*" but they agreed on engaging with it in the future. The senior architect stated: "*our BIM methodology that we have to develop it all the time (…) because all the partners are also* *improving their methodology"*. This partnership plans to considerably refine both their future BIM and SCM strategies.

Table 7 summarises the reflections from the built cases (cases B, C, E), in support for the paragraphs above. The narratives are organised around the most common applications of BIM and SCM, previously presented in Tables 4 and 5. In case B, all partners were equally enthusiastic about both BIM and SCM, and they presented the highest level of SC cultural alignment. Case C displayed a balanced vision for BIM and SCM practices. Case E had a disproportionate focus on BIM over SCM, although BIM was not implemented in its full capacity. For example, the contractor was more BIM- than SCM-driven, whereas the architect was equally SCM-driven and BIM-enthusiast. In all cases, BIM played a role in facilitating the popular SCM activities, such as selecting partners, ensuring quality and sharing information (Table 7).

Papadonikolaki, E; Vrijhoef, R; Wamelink, H; (2016) The interdependences of BIM and supply chain partnering: empirical explorations. Architectural Engineering and Design Management, 12 (6) pp. 476-494. 10.1080/17452007.2016.1212693.

Table 7: Convergent testimonials about areas of improvement from BIM-enabled SC partnering (built cases).

	Activity	Case B	Case C	Case E
SCM	Partner sourcing	*"In the future, we will try to involve the suppliers who are SC partners even earlier in the design process"* (Contractor)	*"For all the sub-contractors, we make contracts, and we ask for BIM models. (…) But also price is important"* (Contractor)	*"When we had to make the selection of the partners, (…) we just let them tell us on a presentation what they understand about SC"* (Contractor)
	Quality management	*"With BIM, everyone wants to optimise their own product"* (Architect) With SCM, we do not have to think which party is less expensive. We strive for quality and because we want to know what we have in common, a kind of blind trust* (Structural engineer)	*"For us, quality is synonymous with BIM use"* (Architect)	*"We view it (BIM) as a method to minimise the faults and improve the quality of the chain"* (Client) *"BIM was more important for quality management than SCM"* (Architect)
	Information exchange	Especially in BIM and SCM, we are much more dependent on information from others* (Steel sub-contractor)	We went back to 2D drawing use for communication; it works faster and efficiently for all* (Cladding supplier)	-
	Cultural alignment	*"Together with the other partners we are learning a lot about BIM"* (Mechanical Engineer) And we know each other, also begin to know each other personally and it is also fun to have this relationship* (Steel sub-contractor)	*"If they (other partners) want to be still preferred suppliers, then that (BIM) is what we want"* (Contractor)	*"We always ask them how they stand. (…) We ask: 'are you ready to show us all the cards?'"* (Contractor)
BIM	3D representation	-	-	*"BIM did play an important part in 3D representation, not just in engineering"* (Architect)
	Design co-ordination	*"With the co-locations was easier than calling to arrange something. We (…) want to sit together more frequently now"* (Architect)	*"The BIM design process, (…) it is not really optimal yet, but we are getting there, (…) we have to make the distance smaller among the partners."* (Architect)	*"That (design co-ordination) went far because of the supply chain, together with BIM"* (Architect)
	Cost estimation	*"In this project we only did the modelling, we did not do a lot of analyses, we want to improve that in the next"* (Contractor)	"All calculations were successful apart one supplier* (Structural engineer)	-
	Clash detection	*"We had a clash session with the concrete supplier and in ten minutes we could be discussing issues all around the building that are influenced by it because the building is so complex"* (Architect)	*"We invite some partners whose responsibility it is and just make clash session only with them. It is faster."* (Contractor) *"Maybe in an ideal process we put all the partners altogether"* (Architect)	-

* Translated from the Dutch by the authors.

Interpretation

Use of BIM within SC partnerships

BIM implementation deeply influenced the SC partnerships. About half of the interviewed firms claimed that adopting BIM was an internal decision, often made since 2000, to serve their intra-organisational need for advanced IT. These firms used it in about half of their projects, included it in their business plans and advertised their BIM-readiness on the market. The other firms stated that BIM adoption was a natural but external decision because they had to meet client and market demands. In case E, the contractor performed an unofficial competition with a brief and presentation among their preferred partners to select the most BIM-savvy firm. Thus, there are both internal and external reasons for why the phenomenon of BIM-enabled SC partnering has unfolded.

In all cases, the SC partnerships were supported, even when non-BIM using partners were selected. The non-BIM users either followed a traditional process or were learning on-the-job. The BIM-using partners of cases A and E helped the less experienced partners during extra BIM training sessions. In case B, the steel sub-contractor, who was an internal SC partner, had hired a BIM drafting company to deliver their input in BIM. However, there was an apparent mismatch on the vision for BIM and its actual implementation, e.g. in case E, the BIM capacity of the SC actors was disproportional and *ad-hoc* BIM collaboration was deployed (see Table 6). Whereas in case B, not all SC actors were BIM-ready (e.g. sub-contractor), but the BIM collaboration was *distributed* and sophisticated.

Use of SCM in BIM implementation

Written regulatory documents, i.e. framework agreements, are standard in SCM practices. The cases also customised their BIM protocols based on the Dutch GBA's BIM Norm (Rijksgebouwendienst, 2012). The SC partners used BIM protocols to define their BIM process aside the existing SC contracts, which defined their financial obligations and rewards. The cases B and D jointly customised the norms to the project needs. The BIM protocols described the BIM-related project goals, modelling stages, LoD, timelines, deliverables, and agreements for their meetings. However, not all cases used the protocols in the same manner, as these are not mandated by the Dutch GBA. There was a mismatch between firm-issued and jointly-decided BIM protocols among the SC actors (see Table 6).

Apart from the written agreements, the SCM practices influenced the physical BIM collaboration. In cases A, B, and D one or more joint meetings with all partners were held, i.e. *BIM meetings*, *BIM Design & Engineering meetings* or *BIM Design sessions*. These meetings resembled the pull-planning sessions, which also took place in cases B, C, and D, as to the setting, informal character, established underlying trust, and consensus-seeking orientation (Figure 3). The BIM meetings were mandatory for all partners invited, held weekly or fortnightly and lasted about two hours. After the sessions, the BIM coordinator, who was often from the contractor (cases A, C, D, and E) or the architect (case B), was responsible for sharing the session results. However, the scheduling, content, and participation in the BIM meetings was varying per case and BIM collaboration pattern (see Table 6).

Figure 3: Typical pull-planning session for construction planning (Case C).

Cumulative case results

The cases offered insights into the adoption and implementation of BIM-enabled SC partnering. Table 8 summarises the results. The first column to the left contains the case identifiers. The next contains information on project type and scale. An analysis of BIM use as to the actors, and applications is shown in the subsequent column. The following two columns show SCM adoption as to the actors and applications. The column before the last contains the description of the observed collaboration pattern of the BIM-enabled SC partnership. The last column to the right contains the reflection from the case narratives about how the interdependent BIM and SCM strategies would be deployed in the future.

Table 8: Findings of the analysis of the selected projects with BIM-enabled SC partnering.

Case description		BIM analysis		SCM analysis		BIM-enabled SC partnering	Reflection
	Type and scale	Actors using BIM	BIM application areas	Internal SC actors	SCM application areas	BIM-based collaboration process	BIM & SCM future strategy
A	MF; L	9/10	7/12	6/10	7/11	Distributed	(Ongoing)
B	Housing, L	9/11	7/12	8/11	8/11	Distributed	Improve BIM strategy
C	Utility; M	6/8	5/12	5/8	6/11	Linear	Improve BIM strategy
D	Utility; S	7/9	6/12	5/9	8/11	Linear	(Ongoing)
E	Housing; M	5/8	4/12	6/8	4/11	Ad-hoc	Improve BIM & SCM

Discussion

BIM implementation in SC partnerships

The study identified three patterns of BIM implementation from the SC partnerships: *ad-hoc, linear* and *distributed*. These patterns emerged from the observations of repeated physical and digital structures and processes, e.g. co-locations, written agreements and information exchange, and to the best of the authors' found knowledge, has not been included in existing literature. Apart from considering BIM implementation as a set of readiness, capability and maturity levels for the involved firms (Succar & Kassem, 2015), BIM implementation entails various repeated patterns of collaboration . The emerged patterns pertain to an inter-organisational level and highlight the potential disparities among firms with different BIM capacity (Mondrup et al., 2012). Moreover, the *ad-hoc, linear* and *distributed* patterns offer more information than the three levels of the well-known UK BIM maturity wedge (GCCG, 2011), because they include not only the format of the exchanged information but also its physical and digital conditions, which emerged from SCM practices. Given that collaboration with BIM requires collective effort, this study contributed on how the firms' BIM readiness, capability, and maturity could be translated into a networked and interdependent environment. For example, case E displayed a mismatch regarding firm-based BIM readiness and BIM implementation among the partnership, given that whereas some firms had past BIM experience; they were exchanging native files with their less experienced partners (Table 6). The above mismatch would potentially suggest implications for the practitioners, since the firms would potentially choose BIM-ready partners to fully utilise the potential of BIM and fine-tune their BIM capacities according to different disciplines and firm sizes (Succar et al., 2012), and the specific project BIM scope.

The *linear* and *distributed* patterns featured an aggregation of reference models in the form of open standards, i.e. IFC. The *distributed* collaboration pattern was considered the most sophisticated because it was additionally supported by pre-defined types of physical interaction. The *distributed* patterns underscored the discussions of Miettinen and Paavola (2014) about the misconceptions for a single BIM, and that the BIM-based information exchange is, actually, asynchronous (Cerovsek, 2011). The *distributed* BIM-based collaboration pattern allowed for quite consistent information flows, via the IFC, and additionally provided the SC partners with the ability to use their preferred software. The three patterns were also directly proportional to the number of BIM application areas of Cao et al. (2014) (Table 8). A surprising finding was that the BIM-based collaboration patterns were not related to the number of undertaken SCM activities (Table 8), which could suggest that BIM implementation in SC partnerships is currently transitioning and that the partners rely heavily on their SCM relations, i.e. shared history and vision, rather then BIM.

Interdependences between BIM and SCM

The reported benefits of BIM are numerous, as Barlish and Sullivan (2012) and Bryde et al. (2013) suggest. This study presented how processes and products used for SCM in contractual long-term SC partnerships could support and improve BIM collaboration to attain the acclaimed BIM benefits for the actors. The cases presented real-world evidence on the use of hybrid practices to support the digital technologies, i.e. BIM (Harty & Whyte, 2010). First, BIM implementation, which requires close collaboration among multi-disciplinary professionals, was supported by on-demand or frequent co-locations (Table 6) (cases B, C, D), and even more frequent co-locations were unanimously desired in the actors’ reflections for the future (Table 7). These meetings could increase the commitment of the SC partners, which accordingly increases trust in the SC partnership (Mentzer et al., 2001). Second, the BIM implementation was supported by quasi-contractual means, usually adopted in SCs. The ‘BIM protocol’, or BIM Execution Plan facilitates the definition of ‘what’ to exchange, LoD, and modelling phases and thus improves the challenges pertinent to design ownership (Cidik et al., 2014). However the protocols in the cases were largely customised and project-dependent. The shared vision, history, and experiences from SCM enriched the definitions of ‘how’ and ‘when’ to interact, e.g. issuing specifications and hosting regular pre-scheduled physical meetings. The use of formal agreements, such as BIM protocols and agreements for using standards (Table 6), could inform the process to achieve consistent information-sharing. Thus, SCM practices enriched BIM with processual (co-locations) and product-related specifications (protocols) for more efficient BIM implementation and collaboration among the actors.

The popularisation of BIM induces changes in the SCM practices. The traditional SC was formed by the interplay of price and trust (Segerstedt, Olofsson, Hartmann, & Caerteling, 2010). Usually a power play and opposite ’forces‘ emerge in the decision-making for inter-organisational IT (Adriaanse, Voordijk, & Dewulf, 2010). There is a consensus that alliances and partnerships would require, among others, IT mechanisms, underpinned by legal and contractual frameworks, to support their operations and collaboration (Dossick & Neff, 2010; Rezgui & Miles, 2010). The contemporary SC is formed not only as to price or quality but also as to BIM-readiness. BIM has become a “prerequisite in delivering integrated construction SC practice” (Mahamadu et al., 2014). BIM adoption shifts from being an external ‘market’ demand towards being an intra-organisational drive. In the cases, the firms sought equally BIM-skilled SC partners. In cases C and E, the contractors and clients apart from their traditional role to drive SC integration were committed to the adoption of BIM (Table 7). Thus, BIM becomes a prerequisite for SC partnering, and accordingly BIM could be considered a new type of IT for practitioners and firms that engage in SCM.

Due to the increased number of involved actors in BIM-based projects, their roles were found to transform, as previously suggested by Sebastian (2011). Mäki and Kerosuo (2015) assess that the changes in rules and division of labour among the project actors from BIM will induce “consequences in the network of other activities of construction”. After all, Nederveen et al. (2010) previously noted that the suppliers could soon assume a more decisive role in the design process. Some unexpected findings of newly-amended roles of the main actors, from BIM-enabled SC partnering, observed throughout the five cases, are:

- The clients requested BIM-based project delivery although it was not clear if BIM would be used for maintenance (cases A, B, D, E).
- The contractor was usually the BIM-coordinator and often offered the infrastructure (physical and digital) for BIM sessions (cases A, C, D, E). In case B, the architect was responsible for this function.

- The architects and structural engineers were BIM-proficient in all cases. The architects usually had the additional task to integrate building information from suppliers that were not using BIM (cases C, D, E).
- Some suppliers and sub-contractors also used BIM because of either internal or external demand (cases A, B, C, D).

Research limitations and applicability

The BIM collaboration patterns that emerged in this study – *ad-hoc, linear,* and *distributed* – may also pertain to non-SCM settings. The recruitment of these cases with BIM-enabled SC partnering was facilitated by the fact that the various actors were already organised in structured relations and their availability to share information for research purposes was collectively and unanimously decided. This collective decision suggests evidence against the arguments that construction SCM entails unilateral control on behalf of dominating firms (Fernie & Tennant, 2013, pp. 1041, 1054). Moreover, the promise of BIM to offer consistent information, through the IFC, aligns with the goal of SCM for consistent information flow. In the future, the SC partnerships or any project teams could be potentially benefited by *distributed* BIM collaboration patterns to achieve balanced inter-organisational collaboration.

The study goal was to explore the current status and interdependences of BIM and SCM. A research limitation was that for research proximity, all projects were located in the Netherlands. However, useful lessons and analogies could be extracted for other countries. The Dutch AEC is highly fragmented and diversified (Bemelmans, Voordijk, Vos, & Buter, 2011; Ozorovskaja, Voordijk, & Wilderom, 2007). About 95% of AEC firms are micro-enterprises or Small-Medium Enterprises (SME) (EC, 2015). The results derived from the projects A and E could be more relevant to countries with larger construction companies (Table 2). The observations from cases C and D could be more relevant to countries with chains of industrialised construction e.g. Finland; given that dry construction suppliers were internal SC partners in those cases. As BIM adoption is quite advanced in numerous countries (Succar & Kassem, 2015), yet not globally accepted, its combination with SCM practices could potentially further diffuse BIM. Likewise, BIM could be a vessel for popularising SCM and SC partnering, which accordingly could deliver greater performance consistency (Gosling et al., 2015). The SC partnerships could act as a 'middle-out' strategy for BIM adoption.

Further issues in BIM implementation

Undoubtedly, BIM has the potential to integrate the AEC lifecycle. Azhar (2011) claims that among the challenges of BIM is finding the adequate time to include wisely the various actors in the process. Eadie et al. (2013) point out that BIM is usually mostly applied in the early stages and gradually less later. Here, BIM was mostly used in design management and construction (for logistics optimisation). BIM was used only sporadically during the initiation phase and the application areas associated with it (Table 5). This ’late’ adoption could be related either to the usually less BIM-ready project initiators, e.g. client and owner, or the fragmented AEC lifecycle during the permission stage that often causes delays. The SC actors of the cases B and C desired denser, better fine-tuned, and more informal interactions. BIM and SCM practices complemented each another and gradually overlapped. Nevertheless, this confirms that “BIM represents a new paradigm for AEC, one that encourages integration of the roles of all stakeholders on a project” and that could promote greater harmony among the project actors (Azhar, 2011). Future research would be required to explore in greater depth the interdependences among actors, processes and the sharing of building product models.

Conclusions

The contribution of this study lies in the analysis of BIM implementation in already structured inter-organisational settings. The observed *ad-hoc, linear* and *distributed* BIM collaboration patterns entailed various forms of physical and digital interactions, quasi-contractual means and types of exchanged information. The three patterns could present implications for policy makers, considering that the existing BIM mandates focus on file exchanges and not explicitly on the processual, product-related, organisational complexities of BIM-based collaboration. These patterns could suggest the ingredients for guiding BIM implementation for construction managers.

The results have demonstrated a conceptual and practical link between BIM and SCM concepts. There has been limited research on BIM implementation from SC partnerships. The SCM practices of the partnerships could be supported by BIM implementation at a technical level and regulate the information flows. Simultaneously, the informal settings of SC partnering could facilitate the BIM implementation process by offering a more trusting environment for collaboration. Subsequently, BIM and SCM concepts were found practically highly interdependent throughout these three BIM collaboration patterns. The study could provide the ground to popularise further BIM adoption from a 'middle-out', i.e. inter-organisational, level with the ultimate goal to improve the exchanged products, complex processes, and inter-organisational relations in AEC.

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